4.5 Alternative Treatment Technology Alternatives

This section describes the available alternative technologies for treatment of UDM, the process for evaluating these technologies, the factors used in the evaluation, and the results of this evaluation with respect to applicability to the Gloucester Harbor DMMP. As discussed in Section 3.0, sediments tested and determined to be unsuitable for open ocean disposal, contain primarily metals and PAHs that exceed MBDS reference values. Alternative treatment technologies were evaluated in the context of their ability to 'treat' these constituents of the Gloucester Harbor UDM.

4.5.1 Screening Process

Alternative treatment technologies and their applicability to the DMMP were evaluated in Phase 1 of the DMMP (Maguire 1997a) and updated in this DEIR.

Data on the technologies were gathered from several sources including the USEPA, US Department of Defense, USACE, Environment Canada, and technology vendors. In addition, the findings of other dredging projects involving contaminated sediments were reviewed including the BHNIP, various projects conducted by the Port Authority of New York and New Jersey, Boston Harbor projects, and several projects in European countries.

The inventory included technology description, treatment cost, and site demonstration information for 14 classes of treatment technologies including: chelation, chemical reduction/oxidation, dehalogenation, fungal remediation, incineration, in-situ bioremediation, pyrolysis, slurry bioreactor, solid-phase bioremediation, solidification/stabilization, solvent extraction, thermal desorption, and vitrification (see Appendix D). An overview of pretreatment, sidestream treatment, and residuals management options was also presented.

As part of this technology assessment, a survey of vendors was conducted to gather current information in several major comparative categories including: ability to treat various contaminant types, effects of sediment characteristics on the treatment process, potential role of the vendor in a sediment decontamination project, capabilities and logistical requirements of the process equipment, and information on current and projected costs. The results of the vendor survey allowed for a comparative evaluation of the technologies using standard criteria.

Specific regulations governing the recycling or reuse of treated sediment have yet to be promulgated in Massachusetts, however DEP has issued an Interim Policy for the management of dredged material proposed for upland disposal (see Appendix B). Currently, proposals for reuse and alternative treatment technologies are evaluated under 310 CMR 16.00 and 19.00 (Appendix J). A Beneficial Use Determination (BUD) process (Figure 4-8) as described in 310 CMR 19.060 determines the acceptability reusing contaminated media (including sediments). Under a separate permitting process, there may also need to be a demonstration of need (Figure 4-9) for the treated product.

The UDM that is treated must have a beneficial end use in order for approval to be granted. The product must be viable, i.e. there must be a practical and marketable use. Also, the product and the treatment process itself must be demonstrated to have no adverse effect on the environment.

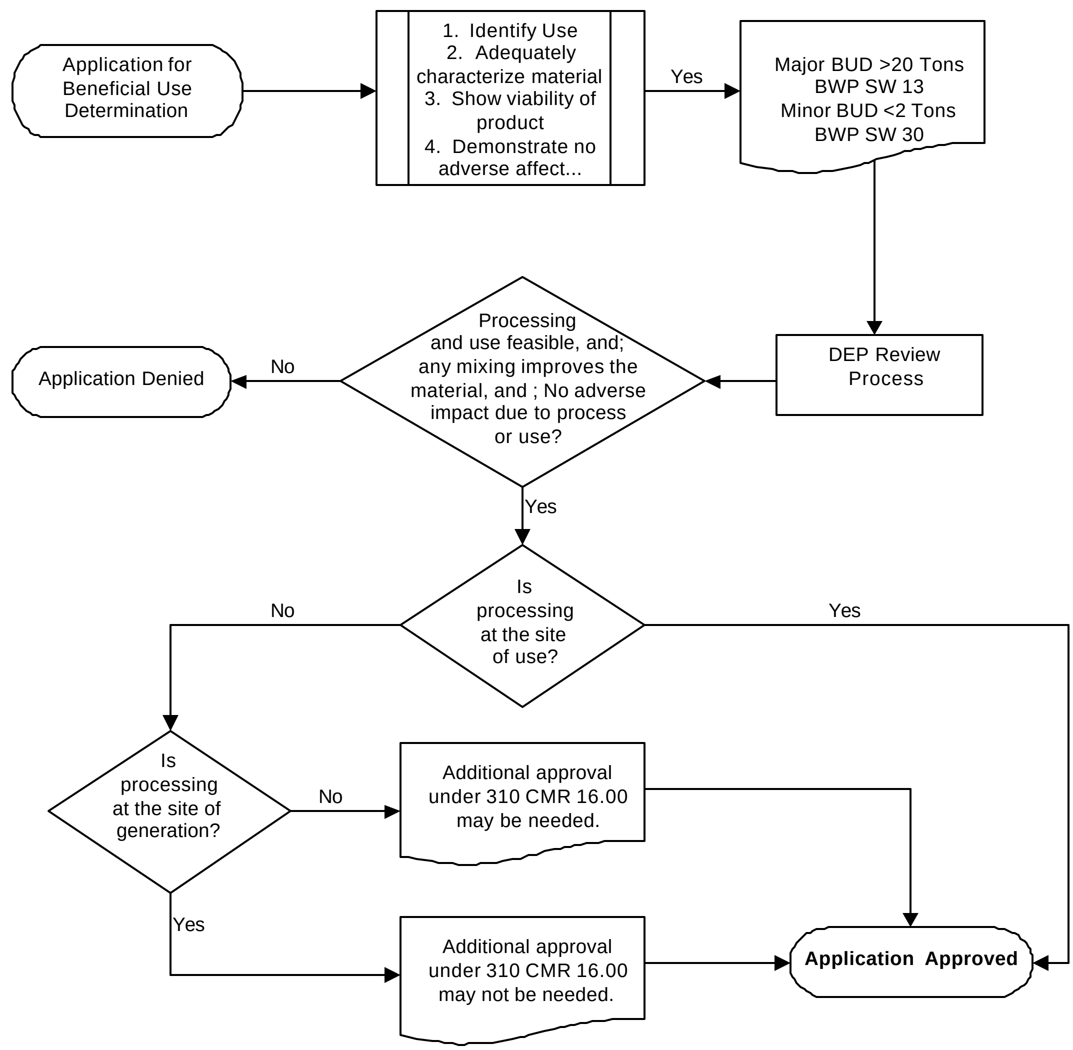

Figure 4-8: Beneficial Use Determination Process

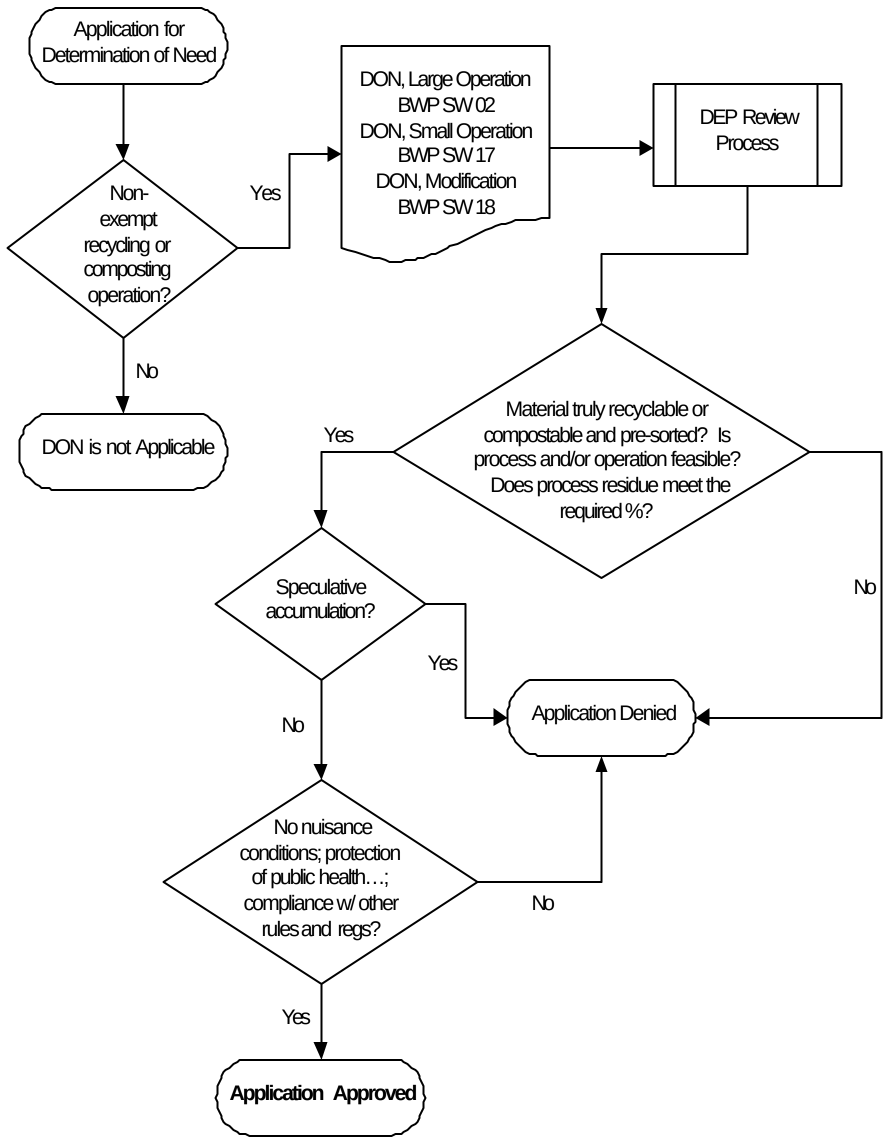

Figure 4-9: Determination of Need Process

4.5.2 Description of Treatment Technologies

This section describes existing sediment decontamination technologies. For each technology, distinct categories of the sediment decontamination process including: pretreatment technologies, treatment technologies, sidestream treatment technologies, and residuals management are also considered.

Pretreatment of the sediment typically involves removal of oversized materials and dewatering prior to treating the contaminated sediment. The control of objectionable odors (which are typically emitted when anaerobic sediment is disturbed), may also be required during pretreatment. Odor control may also be required during the treatment stage of UDM management.

Treatment of the sediment involves application of the primary decontamination process (e.g., physical, chemical, biological, and/or thermal) to reduce, destroy, or immobilize the target contaminants present in the sediments. Treatment may include use of a single technology or use of multiple technologies (i.e., treatment "train" or sequence) in order to address the widely-varying contamination and sediment types.

Sidestream treatment is often required for sidestream wastes (e.g., offgas, particulate emissions, and wastewater) generated during the primary sediment treatment process. These sidestream wastes typically require special handling, treatment, and/or disposal.

Residuals management involves the special handling of treated solids from the primary sediment treatment process that may be acceptable for reuse or contain residual contamination which warrants special management and disposal.

The capabilities and costs of the treatment technology are the main consideration in the selection of a sediment decontamination method. Because sediments often contain a mixture of contaminants, the ability of a treatment technology to handle widely-varying contaminant and sediment types is very important. There are many technologies that will treat a specific contaminant in a relatively inexpensive manner, but require the addition of other technologies in a treatment train to handle a range of contaminants. Use of a treatment train increases the costs, handling requirements, potential environmental exposure, and complexity of sediment decontamination. On the other hand, some individual technologies may be more expensive, but can treat a full range of contaminants. Although the treatment process normally represents the major portion of the costs of sediment decontamination, the total costs including pretreatment, sidestream treatment, and residuals management must be considered when choosing between treatment alternatives. Public concerns about sidestream discharges, especially air emissions, can preclude the selection of certain treatment technologies.

As mentioned in Section 2.1, the treatment technology information contained in this section was gathered from previously-published sources. All data on costs, treatment efficiencies, and reference sites were taken from the SEDTEC (Environment Canada, 1996) and VISITT (EPA, 1996) databases. For those technologies without costs or reference sites, no datum was available in VISITT or SEDTEC.

Table 4-2 presents average values of the treatment rates and costs for the treatment technologies described in this section as well as the total number of vendors for each technology listed in the SEDTEC and VISITT databases. The average treatment costs range from $42/cy for in-situ bioremediation to $462/cy for vitrification. The average cost for all of the technologies considered was $179/cy. These costs are strictly for comparative use and should be considered preliminary estimates only. Costs are subject to high variability based on the uncertainties associated with the widely-varying contaminant and sediment types, concentrations, and site-specific conditions.

Table 4-2: Cost and Production Rates of Treatment Technologies

Technology	Treatment Rate (tons/hr)	Average Cost (per cubic yard)	# Technologies per Category
Chelation	16	$83	1
Chemical Reduction/Oxidation	172	$232	8
Dehalogenation	76	$263	15
Fungal Remediation	ND	$215	2
Incineration	10	$243	8
In-Situ Bioremediation	135	$42	22
Pyrolysis	9	$262	3
Slurry Bioreactor	17	$223	12
Soil Washing	32	$89	19
Solid-Phase Bioremediation	62	$62	51
Landfarming	ND	$48	2
Composting	40	$73	7
In-Vessel Bioremediation	1	$154	3
Solidification/Stabilization	40	$99	1
Thermal Desorption	27	$177	52
Vitrification	3	$462	17
Solvent Extraction	37	$182	21

ND = Not enough data
Source: Environment Canada, 1996 and EPA, 1996

4.5.2.1 Chelation

This process is a form of chemical stabilization that immobilizes metals. Chelation, or complexation, is the process of forming a stable bond or complex between a metal cation and a ligand (chelating agent). Chelating agents, or ligands, may form a single bond (monodentate) or multiple bonds (polydentate) with the target cation. The more bonds formed, the more stable the resulting complex and the greater degree of immobilization of the metal contaminant within the complex. Edetic Acid (also known as Ethylenediamine- tetraacetic acid, or EDTA) is a commonly used polydentate chelating agent. Process efficiency is ion-specific depending upon the chelating agent, pH, and dosage.

The chelation process for metal immobilization may reduce the leachable metal concentrations adequately to meet the Toxicity Characteristic Leaching Procedure (TCLP) requirements. The TCLP determines the leachability of contaminants from a waste material. This testing procedure is used to determine if a waste is classified as “hazardous” based on its potential toxicity. Treated sediments are the only residuals generated by the chelation treatment process. Sidestream waste produced from this treatment strategy consists of wastewater generated during the dewatering of the treated sediments. Costs given by the vendor listed for chelation treatment are $83 per cy.

4.5.2.2 Chemical Reduction/Oxidation

Chemical Reduction/Oxidation technology uses chemical additives to detoxify target contaminants by conversion into less toxic or immobile forms. Chemical oxidation processes work by transferring electrons from the contaminant to the oxidizing agent. During this process the oxidizing agent, itself, becomes reduced. Typical oxidizing agents used in this remediation strategy include various forms of chlorine, potassium permanganate, hydrogen peroxide, persulfate, and ozone. These chemical oxidants may be catalyzed by ultraviolet radiation or other transitional metal additives to form free radicals, thereby enhancing their oxidation potential.

Typical treatment efficiencies for selected organic contaminants may attain 90 to 95% removal. Sediment residuals contain excess chemical agents, reaction by-products including dissolved gases that may require post-treatment monitoring prior to backfill. Sidestream wastes include wastewater from dewatering of the treated sediments and off-gas from the treatment vessel. Wastewater can be recycled into the extraction process. Costs for reduction/oxidation treatment range from $39 to $2,805 per cubic yard ($35 to $2,550 per ton) with an average cost of $232 per cubic yard ($211 per ton) (neglecting the highest value). In Europe, reduction/oxidation is only used as part of a soil washing train, after removal of fine particles. Treatment residual consists of treated sediment.

Limitations include:
- Incomplete oxidation may lead to the formation of intermediate contaminants that are more toxic than the original;
- Dewatering is required before and after treatment;
- High organic matter content increases the required reagent dosage;
- Potential foaming and gas emissions of treated products; and,
- Presence of non-target compounds may react with the reagent additives to increase the treatment cost.

4.5.2.3 Dehalogenation

Dehalogenation is a process which destroys or removes some of the halogen atoms from halogenated aromatic compounds such as polychlorinated biphenyls (PCBs), dioxins, furans, and pesticides by substitution of bicarbonate or glycol for the halogen (usually chlorine) atoms. The two most common dehalogenation treatment processes are base-catalyzed decomposition (BCD) and glycolate dehalogenation. The BCD treatment process combines a sodium bicarbonate reagent with the dewatered UDM within a heated oil matrix to remove the halogen atoms from the target compound (e.g. chlorine atoms on the compound are exchanged for sodium atoms). The glycolate dehalogenation process uses a combination of alkali metal and polyethylene glycol reagents to degrade halogenated organic compounds such as PCBs, dioxins, pesticides, and chlorobenzenes.
Costs for dehalogenation range from $220 to $330 per cubic yard with an average of $263 per cubic yard. Sidestream wastes generated by the BCD process include the reaction media (oil with biphenyls, olefins, and sodium chloride and steam vapor that may contain volatile organic compounds. Sidestream wastes generated by the glycolate dehalogenation process include process water containing water-soluable glycol ethers, hydroxylated compounds, alkali metal salts, and water (steam) vapor that may contain volatile organic compounds. Incomplete or ineffective dehalogenation can produce intermediate toxic daughters which can be more persistent than the original contaminant.

4.5.2.4 Fungal Remediation

Fungal remediation is a particular subset of bioremediation that employs fungi rather than bacteria to degrade the contaminant. White rot fungus is the most commonly studied fungus because the enzymes secreted by the white rot fungus can degrade lignin, the complex organic building block of wood. White rot fungus has shown the ability to destroy complex organic compounds such as explosives, pesticides, PAHs, and PCBs. Although the potential of white rot fungus has been known for over 20 years, there have been few commercial applications of this remedial technology.

Treatment efficiencies of approximately 50% have been reported. Costs for the two vendors offering fungal remediation are $165 to $264 per cubic yard. Residuals include the treated sediments. No sidestream wastes are generated during this treatment process.

Limitations include:

- High contaminant concentrations may be toxic to the fungus;
- Does not treat metals;
- Unknown how salt water will effect white rot fungus;
- Short life of cultured fungi may require frequent reactor replacement; and,
- Removal efficiencies of approximately 50% are considered too low to effectively treat contaminated sediments (the concentration of contaminants may not meet upland disposal criteria).
- Need for continuous monitoring to ensure that fungal population is thriving

4.5.2.5 Incineration

Incineration is one of the most commonly-used remediation technologies. Incineration, or thermal oxidation, destroys contaminants using high temperatures in the presence of oxygen and is effective in destroying a wide range of organic contaminants. Currently in Massachusetts, incineration of wastes is not looked on favorably by the DEP, environmental groups, or the public. It would be very difficult to site an incineration facility in Massachusetts as evidenced by recent efforts to site a portable thermal oxidizer for treatment of 30,000 cy of soil near Logan Airport. Other efforts, such as the proposed incineration of PCB-laden sediments from New Bedford Harbor in the early 1990s were also thwarted due to potential air quality impacts.

Treatment efficiency of the incineration process generally exceeds 99.99% and can be as high as 99.9999% when required for PCBs and dioxin. Costs for incineration range from $55 to $880 per cubic yard with an average cost of $243 per cubic yard. Incineration costs increase for PCBs and dioxins. Ash is produced as a residual material. This ash typically contains high heavy metal concentrations and therefore may require further management/ treatment. Sidestream wastes produced include air emissions and waste water (the latter generated as a by product of the air emission control systems required to operate an incinerator).

Limitations include:
- Requires a very low moisture content in sediments;
- Strict feedstock particle size limitations (1 - 2 inches maximum);
- Gaseous discharges are a major potential contaminant emission pathway;
- Heavy metals are not removed or destroyed and are more leachable after incineration;
- Metals can react with chlorine or sulfur to form more toxic compounds;
- Incomplete combustion of PCBs may produce more toxic dioxins;
- Public opposition;
- Permitting difficulties;
- Large area required for equipment layout; and,
- Residual material requires further management.

4.5.2.6 In-situ Bioremediation

In-situ bioremediation is a process in which indigenous or inoculated microorganisms (i.e., fungi, protozoa, bacteria, and other microbes) degrade organic contaminants found in the sediments. In the presence of sufficient oxygen, microorganisms may ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen, the contaminants may be ultimately reduced to methane, carbon dioxide, and trace amounts of hydrogen gas. In-situ bioremediation processes have been successfully used to treat petroleum hydrocarbons, certain solvents, pesticides, and other organic chemicals. No residuals or sidestream wastes are produced since the treatment occurs in-place. However, sometimes contaminants may be degraded to intermediate products that may be equally, or more hazardous and persistent than the original contaminant.

Treatment efficiency of the in-situ bioremediation process generally exceeds 90% and can be as high as 99%. Costs for in-situ bioremediation range from $6 to $116 per cubic yard with an average cost of $42 per cubic yard.

Limitations include:

- Extended remediation times on the order of years to decades;
- High concentrations of heavy metals and contaminants may be toxic to microorganisms;
- Bioremediation slows at low temperatures;
- Not all organic compounds are biodegradable;
- Bioremediation rates are limited by the concentrations and bioavailability of PAHs, PCBs and pesticides in the sediments; and,
- Heterogenous geological conditions and low permeability soils (less than 10^{-5} cm/sec) are not favorable for in-situ bioremediation.

4.5.2.7 Pyrolysis

Pyrolysis involves the destruction of organic material in the absence of oxygen. The absence of oxygen allows separation of the waste into an organic fraction (gas) and an inorganic fraction (salts, metals, particulates) as char material. Pyrolysis is normally used to treat high concentrations of organics (e.g., semivolatile organic compounds and pesticides) that are not conducive to conventional incineration. Residuals produced by the pyrolysis process consist of ash, often containing heavy metals. Sidestream wastes include air and wastewater. Air emissions typically contain carbon monoxide, hydrogen and methane. Wastewater is via pretreatment dewatering and via the second stage of the pyrolysis process when pyrolytic gases (produced during primary treatment) are destroyed in a secondary reaction chamber. The wastewater is generated by a scrubber system which removes particulate contaminants from the pyrolytic gases prior to release to the atmosphere. The wastewater may contain hydrogen, methane and some hydrocarbons.

Treatment efficiency for the pyrolysis technology generally exceeds 99%. Costs for the two vendors offering pyrolysis are $248 and $275 per cubic yard. Major factors affecting this estimate are the condition and properties of the feed sediment (i.e., moisture, total contamination, and soil characterization).

Limitations include:

- Requires a very low moisture content (<1%) in sediments (which requires pretreatment dewatering and sidestream wastewater requiring further treatment);
- Strict feedstock particle size limitations;
- Gaseous discharges are a major potential contaminant emission pathway;
- Heavy metals are not removed or destroyed, but are not more leachable after pyrolysis;
- Public opposition;
- Permitting difficulties; and,
- Site space limitations.

4.5.2.8 Slurry Bioreactor

A slurry bioreactor is a controlled biological treatment vessel where the contaminated sediments are treated in a slurry form at a low solids content. The sediment is mixed with water to a predetermined concentration dependent upon the concentration of the contaminants, the rate of biodegradation, and the physical nature of the sediments. Slurry bioreactors can treat a variety of organic contaminants including chlorinated and non-chlorinated volatile organics, PAHs, PCBs, and pesticides.

Typical treatment efficiencies of greater that 90% can be attained in a slurry bioreactor. Treatment costs range from $6 to $825 per cubic yard with an average cost of $223 per cubic yard. Treatment residuals include processed soils. Sidestream wastes include wastewater from dewatering the treated slurry and off-gas from the treatment vessel.

Limitations include:
- Heavy metals at high concentrations can inhibit microbial degradation;
- Treatment and disposal of wastewater from slurry dewatering;
- Dewatering is required after treatment;
- Equipment operation and maintenance is intensive;
- Higher energy costs than solid-phase bioremediation;
- Organic destruction efficiencies are generally low at low concentrations; and,
- Low cleanup standards may be difficult to meet for recalcitrant organics.

4.5.2.9 Soil Washing

Soil washing refers to the process of using water to physically separate the sediments by particle size into a reusable bulk fraction and a smaller fraction containing concentrated contaminants. Since organic contaminants are often sorbed to the finer silt and clay particles, separation of this fine fraction from the sandy sediments allows reuse of the typically non-contaminated sands and accomplishes a volume reduction of the total contaminated sediment mass. It is also possible to amend the wash water with surfactants to aid in dispersing soil particles; and chelating agents, acids, or bases to separate the contaminants from the sediment. Soil washing has the potential to treat a variety of contaminants including PAHs, PCBs, fuel oil, heavy metals, radionuclides, and pesticides.

Typical treatment efficiencies are greater than 90% for volatile organics, 70 to 95% for metals, and 40% to 90% for semivolatile organics. The cost of soil washing ranges from $20 to $220 per cubic yard with an average cost of $89 per cubic yard. Residuals include a sand fraction, a suspended fine particle fraction and a remaining soil fraction. The waste stream includes wash water with amendments and suspended fines.

Limitations include:
- Soil washing is only marginally effective for sediments composed primarily of clays and silts;
- Maximum particle size typically 0.5 cm;
- Removal of fines from wastewater may require the addition of polymer flocculent;
- Treatment and disposal of water from pre-treatment dewatering;
- Treatment and disposal of amended washwater,
- Treatment and disposal of post-treatment dewatering.

4.5.2.10 Solid-Phase Bioremediation

Biological degradation of contaminants is a naturally-occurring process. Bioremediation is the acceleration of the natural biodegradation processes by controlling moisture content, temperature, nutrients, oxygen, and pH to create the optimal environment. For purposes of this discussion, the varieties of solid-phase biological treatment processes have been divided into three categories based on level of engineering:

landfarming, composting, and in-vessel bioremediation. Solid-phase biological treatment technologies are used primarily to treat VOCs and petroleum hydrocarbons. It is also possible to treat PAHs, PCBs, halogenated organic compounds, explosives and pesticides to some degree, especially in the more highly-engineered in-vessel systems.

Costs for all solid-phase bioremediation technologies range from $3 to $264 per cubic yard with an average cost of $62 per cubic yard. Solid-phase bioremediation is used on a production scale in Europe, especially in The Netherlands, Germany, and France.

4.5.2.11 Landfarming

Landfarming is the least engineered of the solid-phase bioremediation treatment processes. Landfarming consists of spreading the contaminated sediments over a large area of land and periodically tilling the sediments for aeration. Environmental conditions are controlled by watering (moisture content), fertilizing (nutrient concentration), tilling (oxygen concentration), and lime addition (pH) to accelerate natural bioremediation. Organic matter is usually added to retain moisture, provide additional nutrients, and as a supplemental food source (bacterial bioremediation). However, the addition of organic matter may increase the volume of the UDM. Temperature cannot be regulated to a great extent, limiting the applicability of landfarming in cold climates. Since oxygen is added by tilling, the thickness of the spread contaminated sediments is limited to the tilling depth; therefore, a large area of land is required for landfarming. Landfarming may also incorporate the use of polyethylene liners to control leaching of contaminants.

Treatment efficiencies are highly variable but generally greater than 90% for contaminants amenable to aerobic bioremediation. The effectiveness in remediating petroleum hydrocarbons has been widely demonstrated. The costs for the two vendors offering landfarming are $44 and $52 per cubic yard.

Limitations of Landfarming include:

- Open landfarming may not be practical in regions of heavy annual rainfall precipitation and/or cold climate;
- Does not remediate inorganic contaminants;
- Inorganic contaminants may leach from contaminated sediments into ground;
- Ineffective for treatment of high molecular weight PAHs and highly chlorinated PCBs;
- Anaerobic bioremediation processes can generate odors;
- Of the solid-phase bioremediation treatment processes, landfarming offers the least control over environmental conditions;
- Of the solid-phase bioremediation treatment processes, landfarming offers the least control over collection of off-gas;
- Of the solid-phase bioremediation treatment processes, landfarming requires the largest space; and,
- Of the solid-phase bioremediation treatment processes, landfarming requires the longest cleanup time.

4.5.2.12 Composting

Composting is the middle level of the engineering hierarchy of the solid-phase bioremediation treatment processes. The two major variations of the composting process discussed here are windrow and aerated static pile. The windrow is a pile typically 6-10 feet high, 15-20 feet wide and hundreds of feet long. Windrows are mechanically turned twice a week to once a year to aerate the pile, control the temperature, and create a more uniformly mixed material. Turning of the pile releases odors. Composting is completed in one month to a few years depending on the contaminants and the level of maintenance of the windrow. Maintenance typically includes maintaining optimal moisture content, temperature, oxygen and nutrient concentrations. Depending on the soil particle size distribution and organic matter content, additional organic matter may need to be added to the UDM prior to composting. This could significantly increase the volume of the UDM to be treated. The treatment residual produced by composting is the treated UDM. Sidestream wastes include off-gas and leachate, each of which may require further treatment/management. Off-gases with objectionable odors may be controlled by composting within an enclosed dome or structure to allow for off-gas collection and control.

Treatment efficiencies are highly variable but generally greater than 90% for contaminants amenable to aerobic bioremediation. The cost of composting ranges from $25 to $198 per cubic yard with an average cost of $73 per cubic yard.

Limitations of composting include:
- A large space is required;
- Questionable effectiveness for treatment of high molecular weight PAHs and highly chlorinated PCBs;
- Requires months of remediation/treatment time;
- Can generate odors; and,
- Collection of off-gas is difficult.

4.5.2.13 In-Vessel Bioremediation

In-vessel bioremediation is the most engineered of the solid-phase bioremediation treatment processes. In-vessel biological treatment is often referred to as in-vessel composting. Here it is discussed separately since this treatment technology allows for easier maintenance of anaerobic conditions. Anaerobic microbial pathways are typically used to degrade aliphatic halocarbons (e.g. trichloroethylene, perchloroethylene, etc.). Treatment consists of placing the contaminated sediment mixture in engineered treatment enclosures, or "bioreactors" with leachate collection systems and aeration equipment. In-vessel composting is completed in a couple of weeks and the pile is normally allowed to cure for an additional one to three months. In-vessel systems allow stricter environmental controls, faster composting times, odor collection and treatment, smaller area requirements, and can handle a wider variety of contaminants. In-vessel techniques also allow for added security measures at the treatment site (i.e.: access to the bio-reactor can be controlled). The treatment residual is the treated UDM. Sidestream wastes include off-gas and leachate, each of which may require further treatment/management.

Typical treatment efficiencies range from 70 to 95%. Typical costs range from $33 to $220 per cubic yard ($30 to $200 per ton) with an median cost of $154 per cubic yard.

Limitations of In-Vessel Bioremediation include:
- Ineffective for remediating inorganic contaminants;
- Difficult to treat high molecular weight PAHs and highly chlorinated PCBs;

- Most expensive of the solid-phase bioremediation treatment processes; and,
- Emission controls for off-gas may be required.

4.5.2.14 Solidification/Stabilization

Solidification/stabilization is effective at immobilizing contaminants and are among the most commonly used remediation technologies. Solidification/stabilization involves mixing reactive material with contaminated sediments to immobilize the contaminants. Contaminants are physically bound or enclosed within a stabilized mass (solidification), or undergo chemical reactions with the stabilizing agent to reduce their mobility (stabilization). Binding of the contaminants to the sediment reduces contaminant mobility via the leaching pathway. A typical treatment process includes homogenization of the feed material followed by mixing of solid or liquid reagents with the feed material in a pug mill. Three specific categories examined in this screening include asphalt, cement, and lime solidification/stabilization.

Solidification is the process of eliminating the free water in a semisolid by hydration with a setting agent or binder. Typical binder materials include cements, kiln dust, and pozzolans such as lime/fly ash. Binders used in Germany and France are bentonite and Portland cement. Solidification usually provides physical stabilization but not necessarily chemical stabilization. Physical stabilization refers to improved engineering properties such as bearing capacity, trafficability, and permeability. Although solidification/stabilization technologies are not generally applied to organic contaminants, physical stabilization can also immobilize contaminants since the contaminants tend to be bound to the fines, which are physically bound in the solidified matrix. Chemical stabilization is the alteration of the chemical form of the contaminants to make them resistant to aqueous leaching. The solubility of metals is reduced by formation of metal complexes, chelation bonds, or crystalline precipitates within the solid matrix, using chemical additives and through control of pH and alkalinity. Anions, which are more difficult to bind as insoluble compounds, may be immobilized by entrapment or microencapsulation. Chemical stabilization of organic compounds is not very reliable. Results of reactions of binders to the contaminated sediment are not always predictable due to varying contaminant types and concentrations within the test material. Therefore, laboratory leach tests must be conducted on a sediment-specific basis.

Asphalt Batching

Asphalt batching is a commonly used technology in Massachusetts and has been proven effective in immobilizing TPH, VOC, and PAH compounds. Contaminated solids are blended with asphalt emulsions in a pug mill. The asphalt-emulsion-coated material is stockpiled and allowed to cure for approximately 2 weeks. Pretreatment requirements include dewatering and size classification by screening or crushing to less than 3-inch diameter. End product can be recycled as a stabilized base material for parking lots or roadways.

Cement Solidification/Stabilization

Cement solidification/stabilization involves mixing the contaminated sediments with Portland cement and other additives to form a solid block of stabilized waste material with high structural integrity. Silicaceous materials such as fly ash may be added to stabilize a wider range of contaminants than cement alone. Cement solidification/stabilization is most effective for inorganic and metallic contaminants.

Lime Stabilization

Lime/fly ash pozzolanic processes combine the properties of lime and fly ash to produce low-strength cementation. Lime stabilization involves mixing the contaminated sediments with lime in a sufficient quantity to raise the pH to 12 or higher. Raising the pH results in chemical oxidation of the organic matter, destruction of bacteria, and reduction of odor. Lime stabilization is commonly used to treat wastewater sludge and is primarily effective for organic contaminants and microbial pathogens.

Typical treatment efficiency of the solidification/stabilization process ranges from 75% to 90%. Costs range from $48 to $330 per cubic yard with an average cost of $99 per cubic yard. Residuals produced from treatment are stabilized blocks of sediment material. Air emissions are the main sidestream waste produced during the treatment operation

Limitations include:
- May not be particularly effective for organic contaminants, particularly VOCs;
- Fine particles may bind to larger particles preventing effective bonding of the binder material;
- Inorganic salts may affect curing rates and reduce strength of stabilized product;
- Organic contaminants may volatilize due to heat generated during the reaction (possibly prompting the need for air emission permits); and,
- High moisture content requires increased amounts of reagent.

4.5.2.15 Solvent Extraction

Solvent extraction is similar to soil washing in that the technology produces a volume reduction of the total contaminated material, however, solvent extraction focuses on extracting the contaminants from the sediments using organic solvents. Contaminated material volume reductions of 20 times or more are attainable. Solvent extraction is targeted primarily at organic contaminants including PCBs, PAHs, VOCs, petroleum hydrocarbons, and chlorinated solvents. This technology is not particularly applicable to inorganics, with the exception of organically-bound metals, which can be extracted. Residuals include the treated UDM, often with traces of extraction solvent. Sidestream wastes include waste water from pretreatment and post-treatment dewatering, off-gas from the treatment vessel, and spent solvent used during the extraction. The solvent is usually purified and recycled.

Treatment efficiencies for the solvent extraction process generally exceed 90% and are typically in the 98-99% range. The costs ranges from $21 to $567 per cubic yard with an average cost of $182 per cubic yard.

Limitations include:
- Less effective for sediments composed primarily of clays and silts;
- Not typically effective for removal of inorganic compounds;
- Treated soil may contain residual concentrations of solvent;
- Maximum particle size 0.5 cm;
- Treatment and disposal of wastewater from dewatering; and,
- Dewatering is required after treatment.

4.5.2.16 Thermal Desorption

The thermal desorption technology employs high temperature to volatilize organic contaminants. Thermal desorption technologies are divided into high temperature and low temperature categories. Thermal desorption is a removal process that applies to contaminants that are volatile at the process operating temperatures. Primary targets of treatment are organic contaminants including PAHs, VOCs, pesticides, and chlorinated solvents. This technology is not applicable to inorganic compounds; however, volatile metals, such as mercury, can be extracted.

High-Temperature Thermal Desorption

The high-temperature process uses temperatures between 600 °F and 1,000 °F. At these temperatures, a greater range of contaminants are volatilized including some metals (which may not be desirable).

Low-Temperature Thermal Desorption

The low-temperature process uses temperatures between 200 °F and 600 °F. The lower temperatures do not volatilize metals. Most commercial low-temperature thermal desorption units are of the rotary dryer or thermal screw design.

Treatment residual is the treated sediment. Sidestream wastes include air and water emissions. Pollution control devices are required to reduce particulates in the air emissions. Water wastes include pretreatment dewatering and wastewater produced by the air pollution control system. Costs for thermal desorption range from $11 to $908 per cubic yard with an average cost of $177 per cubic yard.

Limitations include:
- Optimal moisture content less than 60%;
- Gaseous discharges are a major potential contaminant emission pathway;
- Feedstock particle size limited to 2 inches maximum;
- Tightly bound contaminants in clayey and silty sediments increase residence time requirements; and,
- Most heavy metals are not removed or destroyed.

4.5.2.17 Vitrification

Vitrification technology uses high temperatures, above 2,900 °F, to melt and convert contaminated sediments into oxide glasses, thus achieving destruction of organic contaminants and stabilization of inorganic contaminants. The resulting glass is nontoxic and suitable for recycling or landfilling as a non-hazardous material. Vitrification technology is applicable to all types of contaminants. Vitrification immobilizes inorganic contaminants in a solidified glass matrix and destroys organic contaminants with the high temperature involved in glass production.

The treatment efficiencies range approach 99% or greater for most target contaminants. Vitrification is one of the most expensive technologies; however, since vitrification can act as a stand-alone technology, the cost of vitrification can compete when a treatment train of other technologies is required. The cost of vitrification ranges from $66 to $1540 per cubic yard with an average cost of $462 per cubic yard.

Limitations include:
- Gaseous discharges are a major potential contaminant emission pathway;
- Creates a glass material that must be reused or disposed;
- More expensive than incineration; and,
- Molten product requires long cooling period.

4.5.3 Screening Factors

To evaluate alternative sediment decontamination technologies, a survey was performed of potential vendors of treatment systems. Potential vendors were identified from the VISITT and SEDTEC databases. Each vendor was provided with a sediment decontamination technology vendor questionnaire to complete either on-line or through the mail. A copy of the questionnaire is provided in Appendix D. The questionnaire was developed and administered in order to obtain information for a comparative analysis of treatment technologies. Results of this questionnaire allowed development of a consistent set of results including site conditions, sediment characteristics, target cleanup levels, treatment options, and cost elements to evaluate sediment decontamination processes and vendors.

The vendor questionnaire was divided into several comparative categories. The major categories included: Business Information, Ability to Treat, Effects of Sediment Characteristics, Vendor Involvement, Process Information, and Cost. These elements, as well as several practicability criteria were applied to each technology. In addition, DEP Solid Waste Management staff were consulted regarding specific case-studies and experience in the application of alternative treatment technologies to dredged material and other media within the Commonwealth (see Appendix K for DEP comments and Section 4.5.4 below for detailed screening).

<u>4.5.3.1</u> <u>Ability to Treat</u>

The ability of the technology to treat the contaminants that may potentially be present in the dredged sediments such as metals, PAHs, PCBs, and TPH is a primary consideration in evaluating treatment technologies. The vendor was asked to categorize their technology for its ability to provide immobilization, removal, destruction, or no effect on the target contaminants. In addition, the typical treatment efficiencies and operating ranges (i.e., low and high contaminant levels) were to be identified. Specific individual contaminant exceptions within each of the four major contaminant groups were also to be identified in this section.

<u>4.5.3.2</u> <u>Effects of Sediment Characteristics</u>

This category contains information about the sensitivity of the treatment technology to variations in the physical and chemical properties and characteristics of the dredged sediments. Requested information included the maximum particle size accepted by the treatment system and the optimal solids content recommended for the treatment system by the vendor. More detailed information was requested on the effects of specific sediment characteristics on the treatment technology. These characteristics included sandy, silty, clayey, low and high moisture content, low and high organic content, and high metals content. Choices provided for describing the effects of the sediment characteristics on the treatment technology included favorable, no effect, impedes, or unknown.

4.5.3.3 Process Information

This category contains information specific to the design and implementation of the vendor's technology. The most critical piece of information in this category is the current scale of development of the technology. Choices included laboratory, pilot, or full/commercial scale. The total number and site-specific references were requested of those vendors with full scale operations. Process-specific information requested included pretreatment requirements, treatment batch size and treatment time, maximum system throughput, residuals generated (e.g., liquid, solid, gas, none), and residual disposal requirements. In addition, any special site- or process-specific needs such as power, water, safety, or permits were to be identified in this section. Other process-specific information included mobilization and demobilization times and layout space required.

4.5.3.4 Cost

The capabilities and costs of the treatment technology, in combination with the time required to process a given volume of sediment (see throughput below), are a key consideration in the selection of a sediment decontamination method. The average cost of sediment decontamination technologies is relatively high ranging from $70 to $170 per cubic yard. In comparison, contaminated sediments from the BHNIP will be disposed of in CAD cells within the footprint of the area to be dredged at an estimated disposal cost of $36 per cubic yard.

4.5.3.5 Throughput

The vendor survey found that the treatment technologies generally have low throughput ranging from 30 to 2,000 cy per day. The treatment technologies evaluated for the BHNIP were rejected partially because the low throughput would constrain the viability of the project. Throughput rates must be considered along with the number of days allowed for dredging and the volume of material to be dredged. In Gloucester Harbor, dredging is allowed only in the late fall and winter months to protect sensitive spawning activities. There are approximately 100 working days (Monday through Friday) in any one dredging season. For a project of 100,000 cy, 1,000 cy of sediment would need to be dredged each day. For smaller projects, slower throughput rates could be adequate, but for large projects, dredging rates of 5,000 - 10,000 cy per day are typical. Ten of the vendors reported throughput rates equal to or greater than 1,000 cubic yards per day, but the majority of processes have much lower throughput rates, in the hundreds of cubic yards per day range .

4.5.3.6 Demonstrated Success

The results of the vendor survey and pilot-scale testing for the Port of NY/NJ cast doubt on the assertion that technologies are not available and proven. The vendors surveyed reported an average of 32 reference sites for full-scale implementation, and approximately half of the vendors reported 5 or more full-scale implementations of their technology. However, the ability of a treatment system to handle widely-varying sediment and contaminant types remains a challenging issue.

4.5.3.7 Logistics

The availability of space, utilities, time, and other logistics are site-specific issues not addressed in this report other than to mention the importance of considering such issues.

4.5.3.8 Permitting Issues

Two issues make permitting of treatment facilities particularly difficult in Massachusetts: sidestreams and residuals management. Public concerns about sidestreams such as gaseous emissions can bring overwhelming opposition to the siting of a treatment facility. Residuals management is discussed separately below.

4.5.3.9 Residuals Management

The costs incurred while managing residuals can easily result in a treatment option that is not economical. In the best case, the residuals can potentially have a commercial value to help offset treatment costs. Based on the documents contained in Appendix C, it appears that there is limited applicability of the following residuals management options: landfill disposal, recycling as landfill cover, and recycling as asphalt material. In addition, the uncertainties associated with the reuse option will greatly limit its applicability until regulations/policies have been promulgated. Although 88% of the vendors claimed that the treated sediments could be reused, it appears based on discussions of specifics with the vendors that many of the potential reuse options are still conceptual and not actually available.

4.5.4 Screening Results

The results of the alternative treatment technology inventory (presented below) were used to evaluate the potential for application of these technologies to sediments to be dredged from the Gloucester Harbor. The survey results are as follows:

- 77% of the technologies are at the full scale/commercial scale of development;
- Vendors offering full scale/commercial technologies have an average of 32 reference sites per vendor;
- Average throughput for all technologies is 754 cubic yards/day (838 tons/day);
- Average treatment costs for all technologies range from $70 to $167 per cubic yard; and,
- The top 4 factors affecting price are: 1) quantity of sediments, 2) moisture content, 3) target contaminant concentration, and 4) characteristics of sediments.

The following is a summary of the practicability of each technology for treating UDM from Gloucester Harbor. Table 4-3 summarizes each technology with respect to the screening factors described above.

4.5.4.1 Chelation

This process is used mainly as a means of controlling leaching of metals but it is not particularly effective on organic compounds or dredged material consisting of silts and clays (which make up a significant portion of the sediments to be dredged from Gloucester Harbor). After chelation, metals leaching, even in sediments containing relatively high heavy metal concentrations, is typically not a problem following upland disposal. Also, chelation is not effective in treating organic contaminants such as PAHs, which are prevalent in Gloucester Harbor sediments. Chelation is relatively inexpensive compared to other treatment technologies ($83/cy), but it requires extensive pretreatment and residuals management.

Table 4-3: Summary of Treatment Technology Characteristics

Technology	Major Advantages	Major Disadvantages
Chelation	relatively moderate cost; excellent for metals treatment	not effective for organics
Chemical Reduction/Oxidation	effective for most organics and inorganics	cost, ineffective for some PAHs, potential toxic residuals
Dehalogenation	excellent removal efficiency for PCBs and chlorinated pesticides	cost, ineffective for metals and PAHs
Fungal Remediation	low technology requirements	low treatment efficiencies, cost
Incineration	high treatment efficiency	permitability, air emissions, cost
In-Situ Bioremediation	high treatment efficiency, relatively low cost	long treatment time, not effective for all organics
Pyrolysis	high treatment efficiency	requires low moisture content, cost, permitability, air emissions
Slurry Bioreactor	effective for treating metals and organics, contained within vessels	cost, ineffective for some organics at low levels
Soil Washing	low technology, relatively low cost	not appropriate for silts and clays
Solid Phase Bioremediation	relatively low cost, low technology	slow process, large land area requirement
Landfarming	relatively low cost, low technology	slow process, large land area requirement, metals not treated
Composting	relatively low cost, low technology	slow process, large land area requirement, low effectiveness for PAHs
In-Vessel Bioremediation	good treatment efficiencies	not effective for inorganics or HMW PAHs, cost
Solidification/Stabilization	reusable residuals (ie: as structural fill), relatively moderate cost, proven track-record for large UDM volumes	ineffective for some organics
Thermal Desorption	high treatment efficiency	requires low moisture content, cost, permitability, air emissions
Vitrification	high treatment efficiency	requires low moisture content, cost, permitability, air emissions
Solvent Extraction	effective in treating organics	not effective for metals, possible toxic residuals, not effective for silts/clays

Key: HMW= High Molecular Weight

PAH= Polycyclic Aromatic Hydrocarbon

PCB= Polychlorinated Biphenyls

UDM= Unsuitable Dredge Material

4.5.4.2 Chemical Reduction/Oxidation

This process is effective in removing inorganics and organics that are present in dredged material. Throughput (172 tons per hour) is relatively high compared to other technologies, however, its cost is high ($232 per cy). For example, a typical marina dredging project containing 10,000 cy of UDM would cost about $2.3 million for treatment alone. Removal rates of 90 - 95% have been reported. Full scale operations have reported relatively low throughput rates of 200 tons/day.

4.5.4.3 Dehalogenation

Dehalogenation processes are engineered to destroy or remove some of the halogen atoms from halogenated organic compounds such as PCBs, dioxins, furans, some solvents and some pesticides, thereby rendering them less toxic. However, these are not the chemicals of concern in the majority of the Gloucester Harbor sediments.

4.5.4.4 Fungal Remediation

This remediation process is relatively inefficient in its remediation capacity (50% removal). The process is not effective in treating heavy metal contaminants and its effectiveness in salt-water media is poorly known. In addition, the average cost is $215 per cy.

4.5.4.5 Incineration

Incineration is one of the most commonly-used remediation technologies. However, there are several disadvantages to this technology, particularly the air emissions generated from the process. Public opposition to incineration has been strong. A small portable thermal oxidizer was proposed to treat 30,000 cy of on-site generated soils (contaminated with petroleum products only) at an isolated area over a mile from the nearest resident near Logan Airport. Public opposition was so strong that the proposal was withdrawn.

There are several technical shortcomings as well: heavy metals are not destroyed and may become more leachable after incineration; the technology is not effective on high moisture content (like sediments); and, gaseous discharges are created as a new contaminant pathway. The average cost is also high at $243 per cy.

4.5.4.6 In-Situ Bioremediation

In-situ bioremediation technologies have been utilized in Massachusetts for treatment of oil and hazardous materials at contaminated upland sites and could potentially be used for contaminated sediment if the intent is to only remediate the sediments in-place. This is not the case for the DMMP as sediments need to be removed to provide safe navigation. Therefore in-situ bioremediation techniques were not considered as a viable alternative treatment technology. Ex-situ bioremediation techniques involve subjecting the UDM to bioremediation techniques at a remote location, following removal from the dredge site. Ex-Situ bioremediation is considered a viable alternative treatment technology. Fungal remediation and various solid phase bioremediation techniques were found to have potential application for treatment of UDM and are discussed individually in this document.

4.5.4.7 Pyrolysis

Pyrolysis is very similar to incineration discussed above, except that it is used to treat very high levels of organics that are not conducive to conventional incineration. Like incineration, low throughput rates and high unit costs as with incineration are encountered with the use of pyrolysis.

4.5.4.8 Slurry Bioreactor

This technology would require pre and post-treatment actions and extensive sidestream controls. Also, its effectiveness in treating low levels of organic contaminants is minimal. Treatment and disposal of wastewater from slurry dewatering is also required. The average cost of this treatment system is $223/cy.

4.5.4.9 Soil Washing

Soil washing is one of the most common methods for treatment of dredged material. It has been used in the United States and is extensively used in Europe. This technology involves two main stages; particle separation, and, washing by water. Wash water amendments such as chelating agents, acids or surfactants can be added to the process to aid in contaminant removal, soil particle dispersal/separation, or both. Despite its real world usage for large volumes of dredged material, soil washing is not effective in treating silt and clay sediments, which comprise the majority of sediments to be dredged from Gloucester Harbor. Sediments that contain a high sand fraction, such as the Annisquam River Channel, could benefit from this technology, but at a cost of $89 per cy.

4.5.4.10 Solid-Phase Bioremediation

This technology includes three basic categories of processes: landfarming, composting, and in-vessel bioremediation. Landfarming and composting require large areas of land to be effective, because the sediment requires thinning and spreading. Landfarming does not remediate metals and is ineffective for high molecular weight PAHs, which is one of the primary contaminant types in Gloucester Harbor sediments. The same limitations are noted for composting. At an average cost of $62 per cy, this is the least complicated and among the least expensive of the treatment technologies.

In-vessel bioremediation is more than twice as expensive as landfarming or composting because it involves engineered treatment enclosures with leachate collection systems and aeration equipment. It too is not effective in remediating metals and is only marginally effective in treating high molecular weight PAHs.

4.5.4.11 Solidification/Stabilization

Solidification is effective at immobilizing inorganic contaminants and is one of the most commonly used remediation technologies. It has been used in New Jersey at several shoreline sites including a site in Elizabeth, where the treated dredged material is being used as structural fill for a new shopping mall.

Solidification/Stabilization technologies are potentially viable treatment strategies for UDM. However, the end product still requires proper disposal/reuse/recycling. That end product can be of a significantly higher volume than the original dredged material because of bulking and the amendments (fly ash, cement, bentonite, lime) that are required to immobilize the contaminants and/or control pH, odor, and sulfide reactivity.

Lime has been used as an additive to dredged material to control nuisance odors and sulfide reactivity in Massachusetts sediments that were dredged and then used as daily or intermediate cover at landfills. This was done on dredged sediments from the Central Artery/Tunnel project in Boston.

These processes are also relatively inexpensive compared to other treatment technologies. Average cost is estimated at $99 per cy, although the unit cost at the aforementioned New Jersey mall site was $56 per cy (ECDC Laidlaw, 1998).

Solidification/Stabilization technologies appear to be the most viable of all available treatment technologies. However, its applicability to the DMMP depends on the large-scale demand for construction fill. Currently, there is no large-scale demand for fill material that cannot be supplied by upland sources. The costs for upland fill material are significantly less than that of solidified dredged material. If the demand for fill material increases over the next 20 years, and the supply of upland fill material decreases, then solidified/stabilized dredged material could become a marketable, cost-competitive commodity.

4.5.4.12 Solvent Extraction

This technology is similar to, and could be used in conjunction with, soil washing technologies to treat contaminated sediments. However, it has a slow production rate (37 tons/hr) and is expensive (average cost $192 per cy). Its effectiveness in treating organic contaminants such as PAHs, PCBs, petroleum hydrocarbons and chlorinated solvents is good, but only for coarse grained materials such as sand. This precludes the use of this treatment strategy for Gloucester Harbor UDM the majority of which is fine-grained (silts and clays) sediment.

4.5.4.13 Thermal Desorption

Thermal desorption is very similar to incineration and pyrolysis and has many of the same characteristic (low throughput rates, high cost). This technology is not effective in destroying inorganics, such as metals. Off-gas from the process needs to be treated before release to the atmosphere.

4.5.4.14 Vitrification

Vitrification is the most effective treatment system available for treating a media that contains a wide variety of contaminants, such as dredged material. Through exposure to 2,900EF heat, the soil/sediment is melted and converted into an oxide glass-like slag that would be suitable for landfilling or recycling. Vitrification, however, is one of the most expensive treatment technologies at an average cost of $462 per cy. Throughput rates are fairly high, with one full scale operation processing 1,500 tons/day.

4.5.5 *Summary of Alternative Treatment Technology Practicability*

Alternative treatment technologies, unto themselves, do not offer any practicable solution to the management of 330,000 cubic yards of UDM from Gloucester Harbor. This is due to several factors, most notably cost and the inability of siting an acceptable dewatering facility. But the costs for some technologies such as solidification and landfarming, even though comparable to the cost of CAD disposal, do not overcome the fact that there needs to be a permanent receiving site for the treated sediment. It is not known at this time, whether treatment of the UDM would be required for disposal at the proposed preferred upland sites. Therefore, more tests need to be conducted. The rationale for deeming the alternative treatment technologies evaluated in the Gloucester Harbor DMMP DEIR impracticable are shown in Table 4-4.

Solidification/Stabilization and soil washing are the only forms of treatment that demonstrate potential feasibility for treatment of Gloucester Harbor UDM, but a receiving site, such as an industrial or commercial development that requires large quantities of construction fill, would need to be identified. Also, the treated UDM must be competitively-priced with upland sources of fill material in order for the use of treatment technologies to be a practicable solution for the DMMP. Currently, the supply of upland fill material exceeds the demand for construction fill, and at a much lower price (approximately $20/cy) than that of even the lowest-priced treatment technology.

4.5.5.1 Potential Future Alternatives

Alternative treatment technologies may prove viable for small projects, those that deal with unique and/or specific type(s) of contaminant(s), or as an element of a larger UDM management technique. Alternative treatment technology is a rapidly growing and evolving field and it is very likely that as ongoing and future pilot and demonstration projects occur, the universe of technically viable, cost-competitive, and permitable alternatives will emerge.

For this reason, the DEIR carries forward all alternative treatment technologies as "potential future alternatives", and specifies through the BUD and DON process, the various general performance standards which an alternative treatment technologies must meet to be seriously considered as a practicable alternative. This flexible approach will provide a baseline from which proponents of alternative treatment technologies can develop and present specific, detailed proposals, and will allow the State to focus its reviews on potentially practicable proposals. This approach is based on the Boston Harbor EIR/EIS. The DMMP will reevaluate, on a five year cycle, the feasibility of alternative treatment technologies for UDM in Gloucester Harbor and other harbors throughout the Commonwealth.

Table 4-4: Reasons Why Alternative Treatment Technologies were Deemed Impracticable

Technology	Rationale
Chelation	Inability to treat PAHs, sidestream wastes, high cost
Chemical Reduction/Oxidation	Inability to treat metals and PAHs, sidestream wastes, high cost
Dehalogenation	Inability to treat metals and PAHs, sidestream wastes, high cost
Fungal Remediation	Inability to treat metals, low removal efficiencies, high cost
Incineration	Inability to treat metals, sidestream wastes, high costs, permitting difficulties
In-Situ Bioremediation	Inability to treat PAHs, sidestream wastes, limited temp. range
Pyrolysis	Inability to treat metals, sidestream wastes, low sediment moisture content required, high cost, permitting difficulties
Slurry Bioreactor	Inability to treat metals, sidestream wastes, dewatering required after treatment, high cost
Soil Washing	Marginally effective for clay and silt sediments, dewatering after treatment required, high cost
Solid-Phase Bioremediation	
Landfarming	Inability to treat metals and PAHs, not suited for cold climates, ineffective on PCBs, sidestream wastes, space intensive, long duration
Composting	Inability to treat metals, space intensive, sidestream wastes, questionable effectiveness PAHs and PCBs, high cost
In-Vessel Bioremediation	Inability to treat metals, sidestream wastes, questionable effectiveness high molecular weight PAHs and highly chlorinated PCBs , high costs
Solidification/Stabilization	Final product volume significantly larger than original dredged material, market demand, high costs
Solvent Extraction	Inability to treat metals, sidestream wastes, dewatering after treatment required, low effectiveness for silt and clay sediments, high cost
Thermal Desorption	Inability to treat metals, sidestream wastes, low sediment moisture content required, long processing time for clay and silty sediments, high cost
Vitrification	Sidestream wastes, long processing time, extremely high cost